NNA12451143R

Statement of Work

Conformal Ablative TPS Manufacturing Scale-Up

Deployable Aeroshell Concepts and Conformal TPS Project

September 20, 2012

National Aeronautics and Space Administration
Ames Research Center
Moffett Field, California

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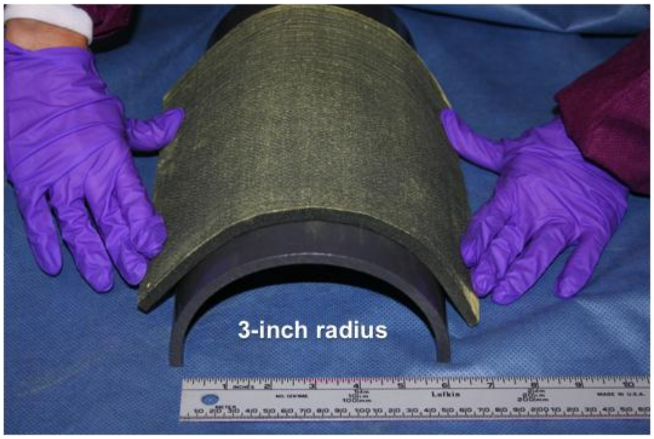
1.0 INTRODUCTION

1.1 GENERAL INFORMATION

NASA has identified the need for research and technology development in the area of Deployable Entry Systems capable of supporting Exploration Class Missions. NASA has established the Deployable Aeroshell Concepts and Conformal (DACC) Thermal Protection Systems (TPS) project based at NASA Ames Research Center (ARC). One element of DACC is the development of a conformal ablative TPS technology targeting missions requiring peak heat-flux around 250 W/cm^2 (CA250). NASA's plan to develop CA250 is the focus of this Request for Proposal (RFQ).



A conformal TPS over a rigid aeroshell has the potential to solve a number of challenges faced by traditional rigid (low strain-to-failure) TPS materials. NASA believes the compliant (high strain to failure) nature of the conformal ablative materials will allow easier integration of the TPS with the underlying aeroshell structure and enable monolithic-like configuration and larger segments (or parts) to be used. By reducing the overall part count, the cost of installation (based on cost comparisons between blanket and tile materials on the Space Shuttle) should be significantly reduced. The conformal ablator design will include a simplified design of seams between gore panels, which should eliminate the need for gap filler design, and should accommodate a wider range of allowable carrier structure imperfections when compared to attachment challenges associated with a rigid ablator material.

NASA ARC is currently conducting an in-house research and development effort to determine the best conformal ablative (CA250) materials. The capabilities goal for the conformal TPS is similar to an MSL design reference mission (~250 W/cm2) with matching pressures and shear environments. Both conformal and flexible carbon-felt based materials have been successfully tested in aerothermal environments above 500 W/cm^2 under the Aeronautics Research Mission Directorate (ARMD) Fundamental Aeronautics Program (FAP) Hypersonics Project and Exploration Systems Mission Directorate (ESMD) Entry Decent and Landing Technology Development Project (EDL TDP), respectively.

The current materials under development are considered Government sensitive information/proprietary. Development of these materials is ITAR and thus is restricted to US companies only. Upon award of a contract, specific processing details will be shared via a non-disclosure agreement.

In general, the materials under development are low density (0.18-0.28 g/cm^3) and are fabricated in a process similar to Phenolic Impregnated Carbon Ablator (PICA) or Silicone Impregnated Refractory Ceramic Ablator (SIRCA) – US Patent #5,536,562 Tran, et al. July 16, 1996. The materials under development at NASA are comprised of:

- A flexible carbon substrate (Carbon felt)
- Infiltrated with an ablative resin system
    - Material 1, phenolic in Morgan Carbon Felt (Conformal-PICA)
    - Material 2, silicone in FMI Carbon Felt (Conformal-SICA)

A test campaign was conducted at the NASA Ames Research Center Arcjet Facility July 24-24, 2012 to evaluate the 2 materials. The test series consisted of two runs in the IHF facility with the 13-inch diameter nozzle. The models were based on SPRITE[1] configuration, Figure 1, to provide a combination of required heat flux, pressure and shear environment and to measure the performance of each of the TPS.

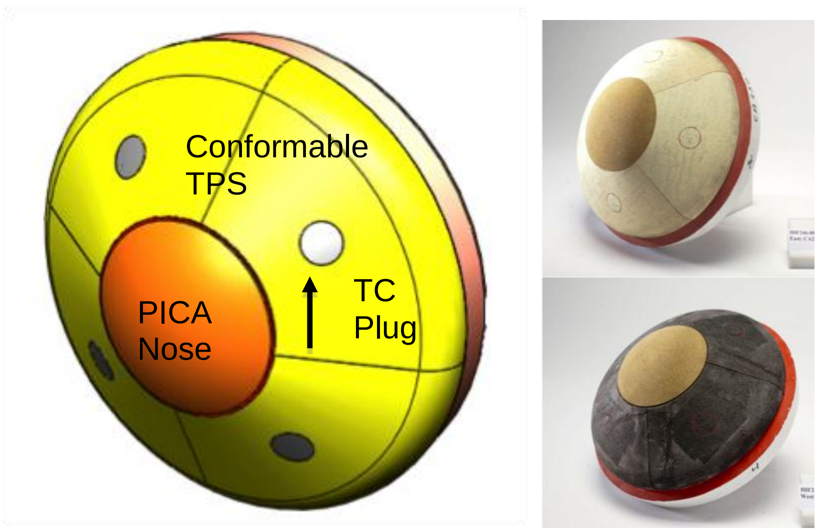


Figure 1. Illustration of the 8-inch diameter, 55° sphere-cone SPRITE 250 test article next to photos of C-PICA (top) and C-SICA (bottom) test articles.

[1] Empey, D. M., Skokova, K.A., Agrawal P., Swanson G., Prabhu, D.K., Peterson K. H., and Venkatapathy E., "Small Probe Reentry Investigation for TPS Engineering (SPRITE)", proceedings , 8th International Planetary Probe Workshop, Portsmouth, VA, 6-10 June 2011.

As mentioned previously, the Conformable TPS element of the DACC project leverages the past investments made by ARMD and ETDD projects and the goal is to develop and deliver a TRL 5 conformable TPS capable of ~250 W/cm^2 for missions such as MSL or COTS missions.

To address the goals of the project, four SPRITE 250 test articles were tested at 2 conditions that were calibrated using 4-inch hemispherical calorimeters prior to model insertion. Expected radial heat flux, pressure and shear for the SPRITE 250 shape are summarized in Table 1.

Table 1. Estimated (CFD) SPRITE 250 heating based conditions.

	Heat Flux (W/cm^2)	Pressure (atm)	Shear (Pa)	Exposure Duration (s)
Condition 1	225	0.14	143	60
Condition 2	483	0.25	230	30

Based on processing experience and arcjet results from the recent test series, NASA has down-selected Conformal-**PICA** for process scale-up. This involves collaboration with an industry partner to demonstrate uniform infiltration of resins into baseline ~1” thick carbon felt on a 1-meter scale and subsequent fabrication of TPS materials by the industry partner for material property characterization.

In FY13, based on the previous year’s effort, development and refining metrics for mission utilization of conformable ablator technology along with assessment for potential mission stakeholders will be carried out. The project will develop and deliver CA250 to TRL 5 by continued material characterization testing that includes thermal, arc jet and structural properties and mid-fidelity thermal response modeling.

The final deliverable will be a 1-m base diameter manufacturing demonstration unit (MDU) designed in collaboration with mission stakeholders and our industry partner (selected in early FY13). Successful engagement with Industry is a key goal for this project element deliverable. Fabrication of the MDU will allow system level technology maturation and demonstration. This exercise is critical in the development of processes and vendors qualified to provide flight hardware.

At the end of 2013, the CA250 project anticipates having matured a conformal ablator TPS to TRL-5 by testing in a relevant environment, developing the model to predict behavior, and demonstrating manufacturability on large-scale systems.

1.2 SCOPE AND OBJECTIVES

This SOW describes the NASA requirements for a contractor who has the **existing** in-house experience, infrastructure and capabilities to manufacture NASA’s selected CA250 material. **This is not a technology transfer**; upon award of a contract, it is expected the selected contractor will sign a Non-

Disclosure Agreement (NDA). The contractor will be then be required to supply small-scale samples for testing followed by large-scale materials for application to the 1-m diameter MDU, as shown in Figure 2. Materials will need to be processed in conically shaped molds. For small scale specimens (55°, 8-in base diameter) molds will be NASA provided and are Teflon. TPS specimens for the large scale MDU must be made on vendor procured mold(s) that will result in 4 gores and a nose section for the 45°, 1-m base vehicle shown in Figure 2.

The vendor is expected to have all necessary vacuum infiltration equipment capable of handling a solution of phenolic and ethylene glycol and vacuum/curing ovens capable of up to **170-200°C and 1 Torr**. NASA will provide funding for chemicals/raw materials and fabrication of a TPS mold for MDU sections. However, the vendor is expected to design (with NASA concurrence) the TPS mold, procure/fabricate the TPS mold and procure all necessary chemicals/raw materials for TPS processing. The vendor will supply NASA with machined specimens (per the Hardware Requirements List). Installation of TPS to the MDU will be performed by NASA personnel.

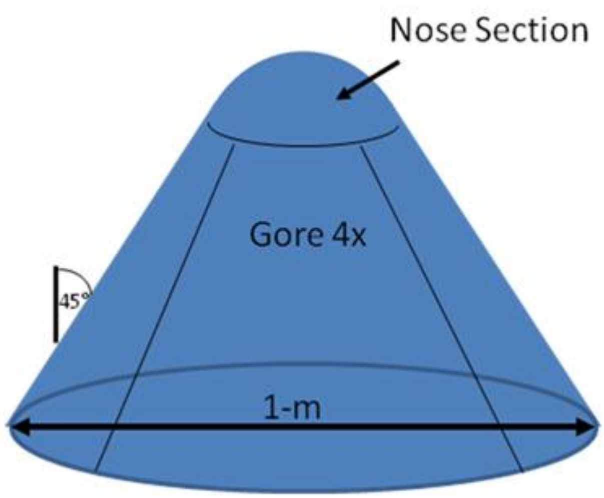


Figure 2 – Schematic of Manufacturing Demonstration Unit (MDU) with notional application of meter-scale conformal TPS segments over aluminum shell substructure.

Specific requirements for contractor capabilities are outlined below and in Section L of the RFP. Responses must also address the more detailed narrative of requirements given in the description of Deliverables, Section 1.3.

Selected contractor shall:

1. Have current capability in heat shield relevant (aerospace grade) TPS manufacturing:
    a. Floor space, infiltrating vessels and vacuum/ovens necessary manufacture the proposed TPS to the 1-m scale
    b. Personnel experienced in making aerospace grade materials
    c. Personnel experienced in designing necessary tooling needed to make MDU
    d. Personnel experienced in appropriate NDE to evaluate material uniformity
    e. Associated product assurance certifications and processing equipment necessary to do so
    f. Certifiable process procedures and specifications
2. Have experience manufacturing *phenolic*-based polymer composites
3. Have experience in working with carbon felts and felt composites
4. Have experience infiltrating resin/solvent into parts >1-m diameter; materials will need to be processed in molds in conically shaped (45°, 1-m base diameter) Contractor is to design and acquire the molds
5. Have the ability to **vacuum infiltrate** and then **remove** large volumes of solvent (*ethylene glycol*) from infiltrated parts prior to and/or during curing (Typical cure conditions 170-200°C and 1 Torr)
6. Have Non-Destructive Evaluation (NDE) techniques available to inspect TPS prior to delivery to NASA
7. Ability to procure necessary chemicals and conduct appropriate quality checks
8. Ability to procure necessary felt materials and conduct appropriate quality checks
9. Ability to take NASA provided processing specification to scale up infiltration process as needed.

1.3 DELIVERABLES

The timeframe for completion of deliverables is less than a calendar year. As such, NASA understands that this scale-up task is a best effort on the part of the vendor and that further process optimizations may be required (at a later date).

1.3.1 Data Deliverables

A description of the data deliverables required in this procurement is provided in Table 1 with descriptions and required test reports shown in the Data Requirements, Section 5, of this document.

Table 1 – Data Requirements List

DR #	Title	Due Date
DR-01	Heatshield Manufacturing Databook	July 31, 2013
DR-02 (Option)	Conformal TPS Material Properties	May 31, 2013

1.3.2 Hardware Deliverables

A description of the hardware deliverables requested in this procurement is provided in Table 2, with specimen descriptions shown in Section 6 of this document. **All hardware deliverable materials will be “1-inch” Morgan carbon felt impregnated with phenolic**. The vendor will need to develop the tooling for the scale-up (MDU TPS Segments).

Table 2- Hardware Requirements List

HR #	Sample Type	Number of Samples	Due Date
HR-01	TPS for Material Properties Testing	2	Jan 28, 2013
HR-02	SPRITE TPS Segments*	24	Jan 28, 2013
HR-02B	SPRITE TC Plugs	24	Jan 28, 2013
HR-03	MDU TPS-Gore Segments	5	May 31, 2013
HR-04	MDU TPS-Nose Segment	2	May 31, 2013

* Molds for SPRITE TPS Segments will be provided by NASA

2.0 APPLICABLE DOCUMENTS

All applicable documents, which will form a part of this contract, are listed herein. The applicable version shall be the current version at the time of contract award. In the event of a conflict between applicable documents and the contents of this SOW, the SOW shall take precedence.

- US Patent #5,536,562 Tran, et al. July 16, 1996 – PICA fabrication process.

3.0 TASK REQUIREMENTS

3.1 GENERAL

NASA's Contracting Officer Technical Representative (COTR) will serve as the primary point of contact between NASA and the Contractor for all technical and programmatic issues related to this SOW. The NASA Contracting Officer (CO) will serve as the primary contact for all contractual issues.

a) The Contractor shall provide management of all resources, schedule, procurement, quality control, and documentation control to deliver the services and products required.
b) The Contractor shall designate a single individual who will be given full responsibility and authority to manage and administer all aspects of the work specified in this SOW, and ensure that all objectives are accomplished within schedule and cost constraints.
c) The Contractor shall designate a single individual who shall serve as the point of contact with the COTR for all technical and programmatic aspects of the contract.
d) The Contractor shall designate a single individual who shall serve as the point of contact with the CO for all contractual aspects of the contract.

3.2 PLANNING AND COORDINATION

The Contractor shall participate in regular technical interchange meetings or other meetings to discuss technical or programmatic issues as requested by COTR. After contract award, the COTR will determine the frequency and the method for progress reporting. Examples of technical interchange meetings expected during this contract are:

- Monthly and/or impromptu telecons to discuss schedule
- Weekly and/or impromptu telecons to discuss unexpected process issues

3.3 SITE VISITS

a) The Contractor shall support and participate in reviews, audits and site visits as requested by the Government. Specific topics and an agenda will be provided to the Contractor at least two weeks prior to the scheduled reviews, audits or site visits.

b) The Contractor shall provide NASA (including Government and non-Government personnel designated by NASA) access to developmental facilities, including subcontractor's facilities, for in-process inspections, audits, meetings and reviews.

3.4 SAFETY, RELIABILITY, AND QUALITY ASSURANCE

3.4.1 Materials Delivery Documentation

The Contractor(s) shall provide copies of test specimen inspection documentation.

3.4.2 Process Assessment

The Contractor(s) shall identify the process areas that could impact the quality of the delivered product such as voids or other manufacturing defects, raw material availability, concerns associated with subcontractors, etc., whose occurrence can cause system failure, hazardous occurrence or otherwise impact the quality of the products to be delivered. The assessment shall be used in developing inspection and/or repair plans and identifying items requiring special handling, testing, or procurement controls. It is expected that this will be a continuous process and shall be updated as required throughout the life of the contract.

4.0 ACRONYM LIST

ARC	Ames Research Center
CA	Conformal Ablator
CO	Contracting Officer
COTR	Contracting Officer Technical Representative
DACC	Deployable Aeroshell Concepts and Conformal TPS
DR	Data Requirements
DRL	Data Requirements List
EDU	Engineering Development Unit
EEV	Earth Entry Vehicle
GFE	Government Furnished Equipment
GSE	Ground Support Equipment
HRL	Hardware Requirements List
HS	Heat Shield
LDDU	Local Design Development Unit
MDU	Manufacturing Development Unit
MSDS	Material Safety Data Sheet
MSR	Mars Sample Return
NASA	National Aeronautics and Space Administration
NDE	Non-Destructive Evaluation
NIST	National Institute of Standards and Technology
OML	Outer Mold Line
PHA	Preliminary Hazard Analysis
QMS	Quality Management System
RFQ	Request for Proposal
RMP	Risk Management Plan
RT	Room Temperature
SDR	Systems Design Review
SE	System Engineering
SOW	Statement of Work
SRM&QA	Safety, Reliability, Maintainability and Quality Assurance
TBD	To Be Determined
TC	Thermocouple
TIM	Technical Interchange Meeting
TPS	Thermal Protection System
V&V	Verification and Validation

5.0 DATA REQUIREMENTS

1. **DR NO.**: DR-001

2. **TITLE**: Heatshield Manufacturing Databook

3. **DATA PREPARATION INFORMATION**:

3.1 SCOPE

The Heatshield Manufacturing Databook (HMD) captures, for the government, a clear and comprehensive summary documenting the approach the Contractor develops to execute the manufacture of conformal ablative TPS in sections ~1-meter diameter. The HMD should cover each step that is necessary in the development of all TPS test materials and MDU components.

3.2 CONTENT

1. Material Fabrication and Qualification

Describe in detail the fabrication processes developed for each heat shield material component. All steps, such as chemical processing, mixing, shaping, curing, autoclaving, hot/warm pressing and vacuuming, shall be included and documented. The identification of when and how all the constituents/ingredients are introduced into the process for each heat shield material component shall also be described. Estimate the time needed to create the heat shield material as a function of size (i.e., volume or acreage area).

Describe limitations of current production techniques or equipment and discuss any changes that will be required to permit fabrication of additional coupons, sectional (joint, gap or seam) units, EDUs, and potential large-scale flight article heatshields.

Discuss necessary infrastructure changes including the addition of facilities, fabrication equipment, personnel or other resources needed to deliver additional coupons, sectional units. If there are costs associated with retention of resources for long durations, specify them.

2. Non-Destructive Evaluation

Describe proposed Non-Destructive Evaluation (NDE) approaches for the heat shield, including minimum size voids or defects that are detectable by the proposed approaches, and justification for heat shield material design tolerance for voids as large or larger than the NDE detectable minimum.

Discuss the inspection of coupons, sectional units, parts, sub-assemblies and MDU. Describe the actual facilities and equipment that will be used to perform these acceptance tests (prior to delivery) and any current limitations on available infrastructure.

3.3 FORMAT

Electronic format (Microsoft® Word or PDF)

1. **DR NO.**: DR-002 (Option, to be exercised via contract modification)

2. **TITLE**: Conformal TPS Material Properties

3. **DATA PREPARATION INFORMATION**:

3.1 **SCOPE**

TPS material properties are used in the development of thermal response models for TPS sizing and heatshield design. As an optional contract deliverable, the vendor may provide testing and a subsequent test report summarizing the results of the material property evaluation of the vendor supplied conformal TPS manufactured under this contract.

3.2 **CONTENT**

Conduct material property evaulations on a minimum of ***5 samples per data point*** for each of the properties listed in the table. Provide a report summarizing test results, describing any anaomolies and provide raw data for analysis by NASA.

Material Property	Property Range	Test Method
Density	Room Temp	Bulk
Thermal Conductivity	RT to 250C	Comparative (ASTM E 1225) or Guarded Hot Plate (ASTM C177)
Heat Capacity	RT to 250C	Adiabatic Drop Calorimetry (ASTM D 2766)
TGA	RT to 1200C	ASTM D 3850
Modulus	Room Temp	ASTM D 4762
Tensile Strain to Failure (IP)	Room Temp	ASTM D 4762
Tensile Strain to Failure (TTT)	Room Temp	ASTM D 4762

3.3 **FORMAT**

Electronic format (Microsoft® Word or PDF)

6.0 HARDWARE REQUIREMENTS

The Contractor shall deliver the following hardware deliverables. For the items described in this Hardware Requirements List (HRL), all communication between the Contractor and NASA shall be initiated with the Contracting Officer's Technical Representative (COTR), unless otherwise directed in the contract.

1 Test Articles and Coupons

Samples of conformal TPS manufactured by the contractor from **"1-inch" Morgan carbon felt impregnated with phenolic** will be used by NASA to evaluate physical, structural and thermal properties. Test articles and coupons required are summarized in the Table below.

Hardware Coupon Requirements

HR #	Sample Type	Number of Samples	Delivery Date
HR-01	Material Prop	2	Jan 28, 2013
HR-02	SPRITE*	24	Jan 28, 2013
HR-02B**	SPRITE TC Plug	24	Jan 28, 2013
HR-03	MDU-Gore	5	May 31, 2013
HR-04	MDU-Nose	2	May 31, 2013

* NASA will provide the molds for SPRITE segments.
** Vendor to provide machined TPS only, no instrumentation.

2 Instrumentation

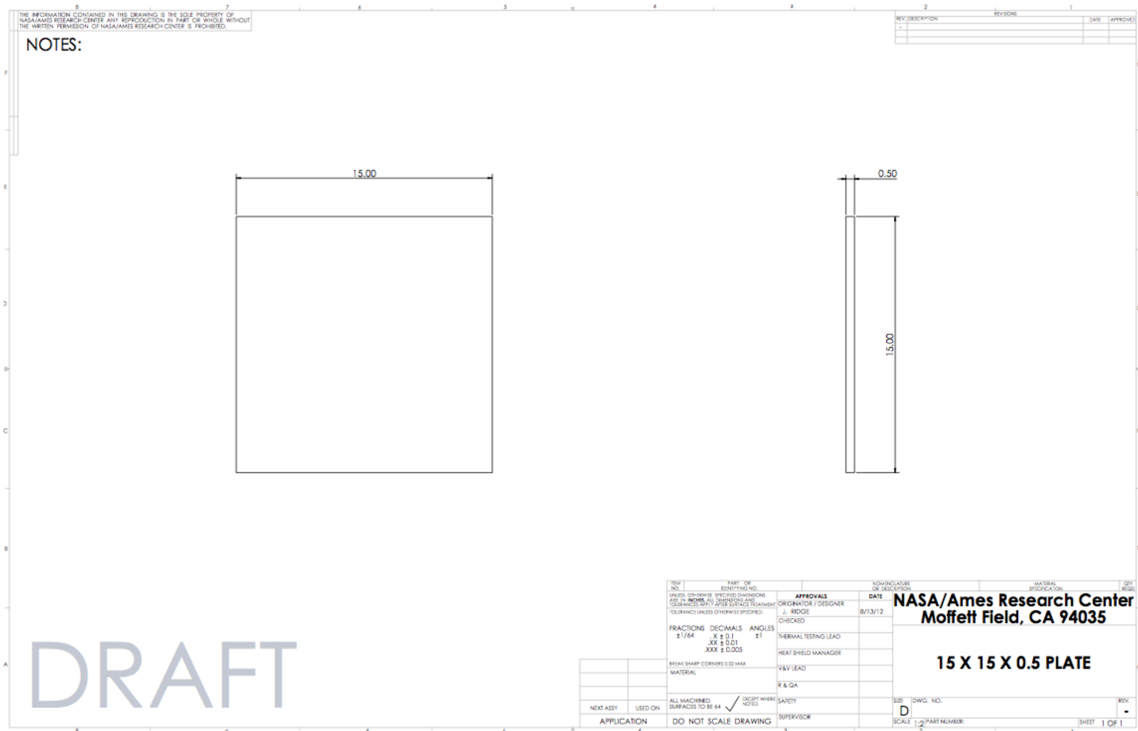
No Instrumentation is required as part of this solicitation.

3 Required Testing and Documentation

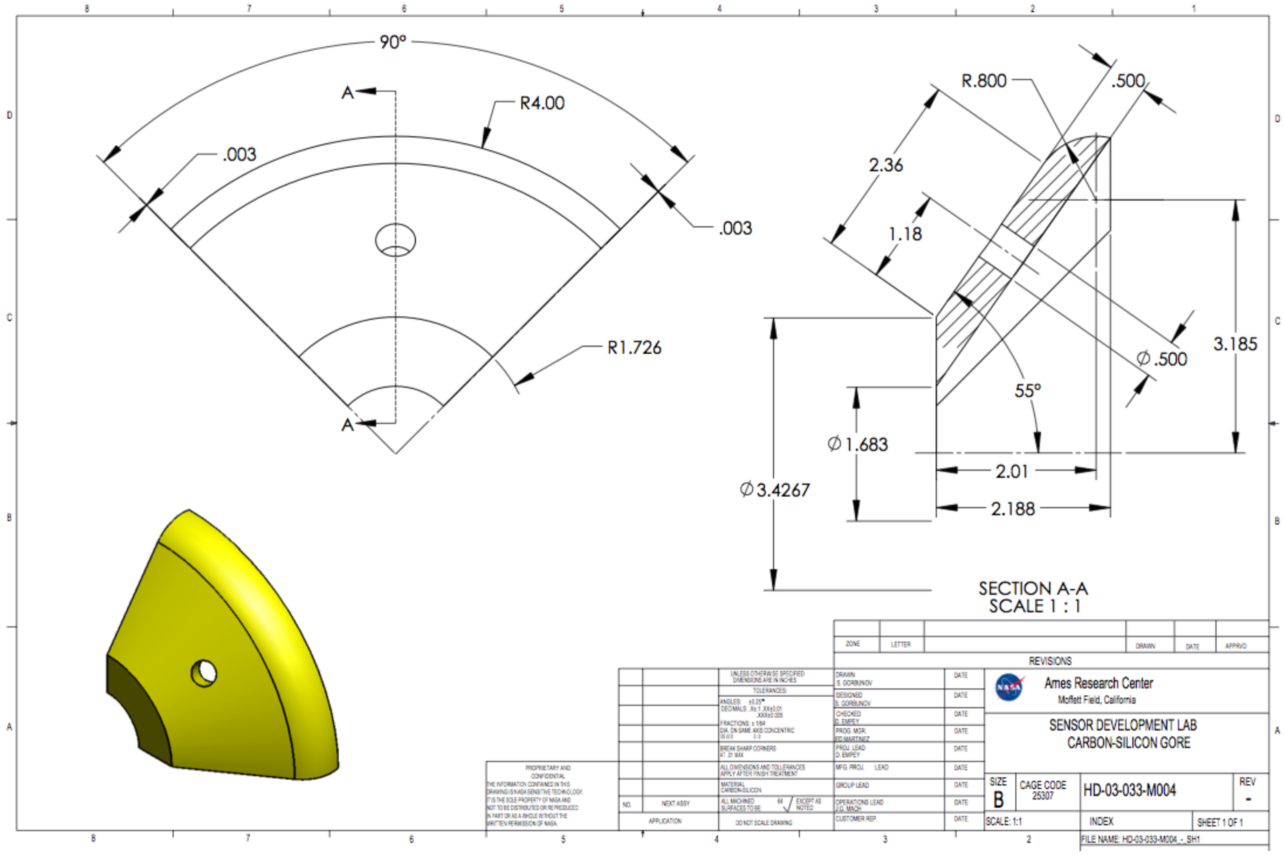
Each test coupon shall be accompanied by the traceability documentation (including unique article identifier, material lot or batch ID, etc.) and certification of inspection and compliance with the acceptance specifications as described below. Any processing non-conformance or other out of the ordinary conditions shall be documented. The Contractor shall provide the following minimum information in tabular format with delivery of their specimens to NASA:

	Requirement	Acceptance Criteria	Units
1	Actual Coupon Weight	Various	g
2	Actual Coupon Dimensions	See drawing tolerances	cm
3	Actual Coupon Density	0.25-0.30	g/cm^3
4	NDE of TPS Coupon *	X-ray Image (Digital File)	N/A

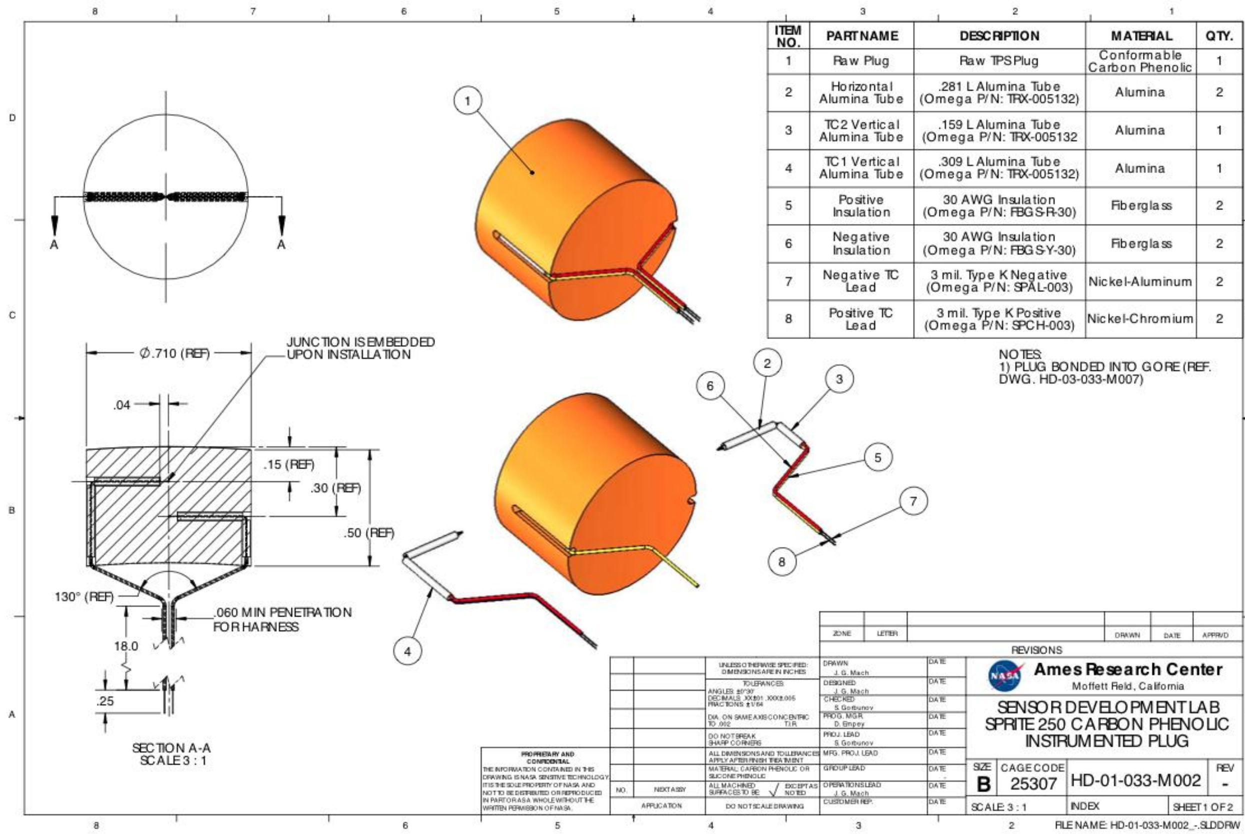
* NDE is best effort. NASA to work with vendor on future acceptance standards.



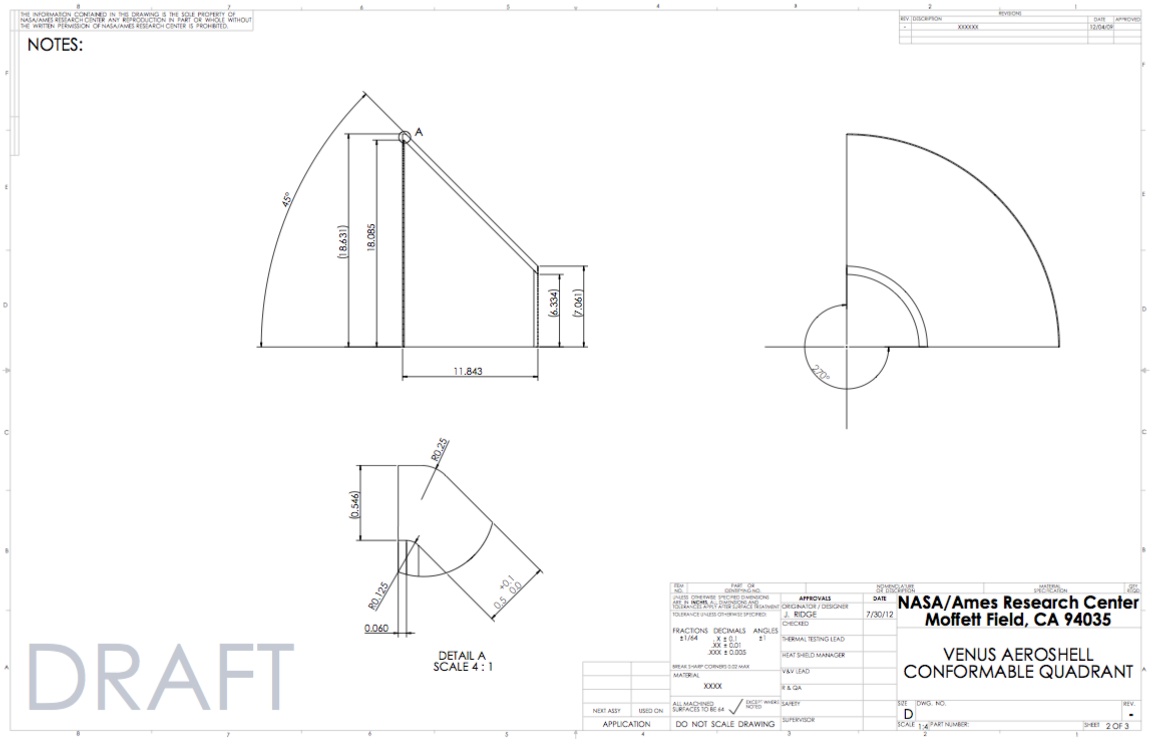
HR-01 Material Property Coupon (15x15-inch)



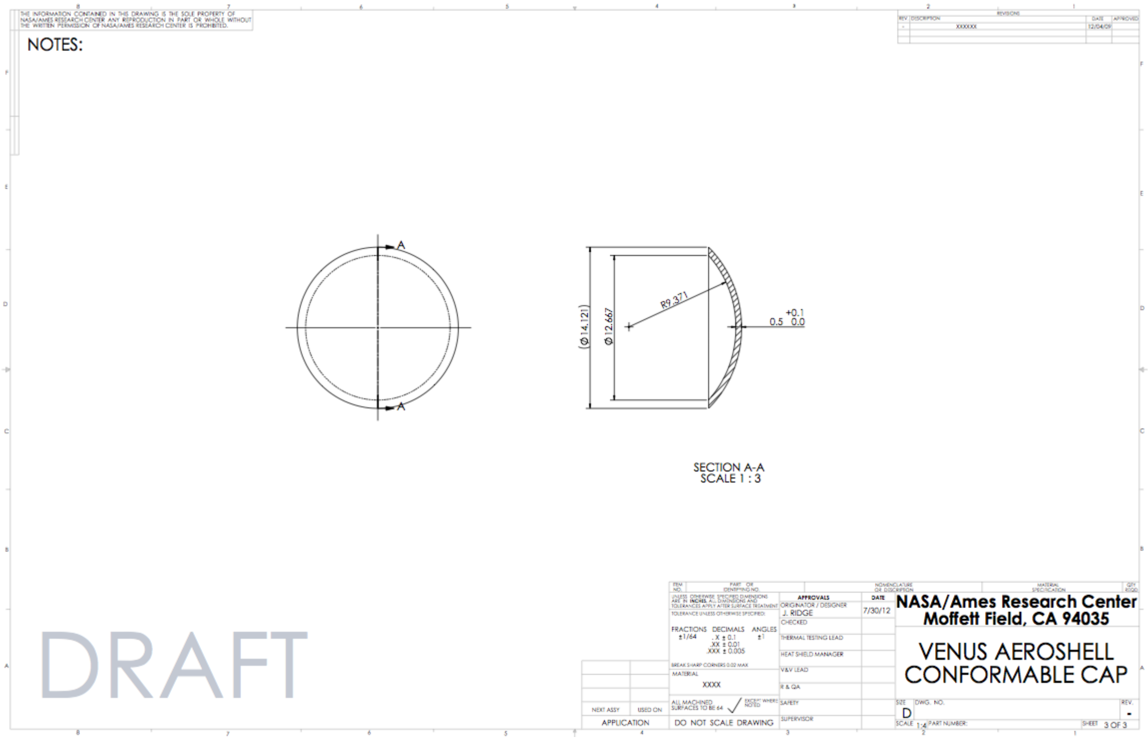
HR-02 SPRITE TPS Segments



HR-02B SPRITE TC Plug



HR-03 MDU Gore



HR-04 MDU Nose Cap